Drift compensation module based on pilot-tone injection.

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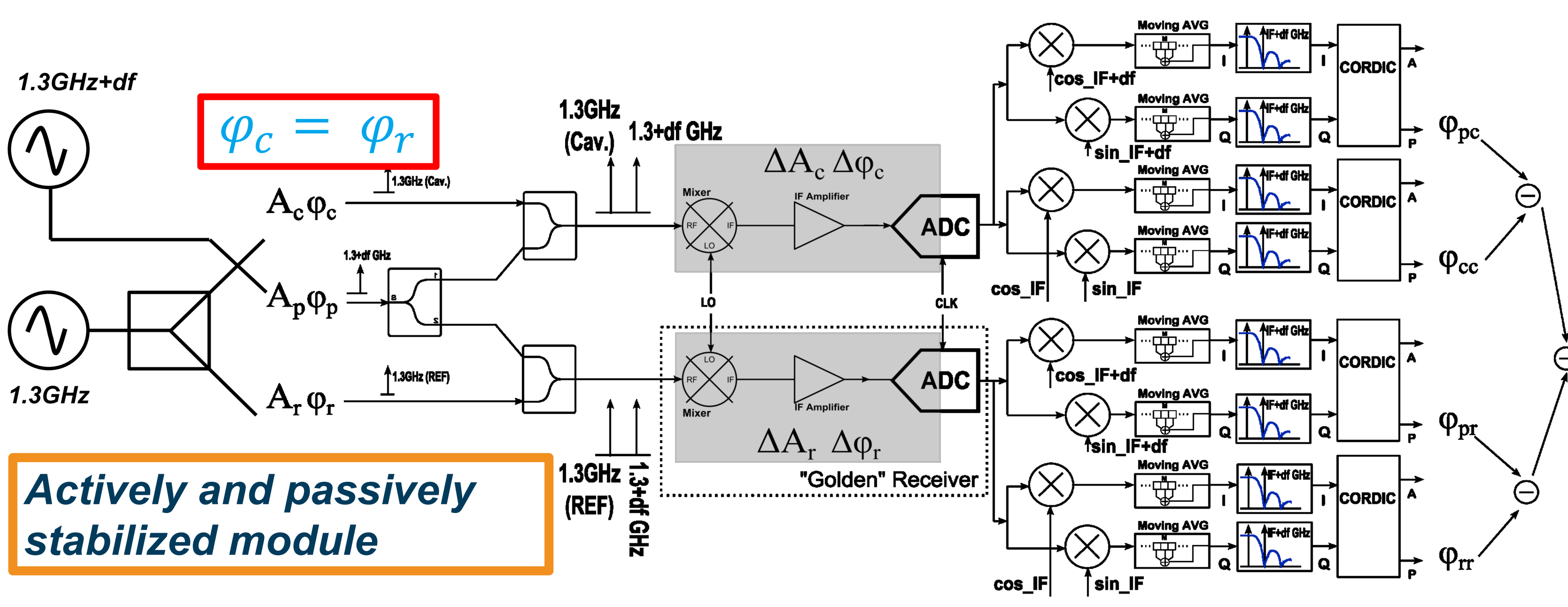
Abstract

In the contribution we present a compact, all-in-one module which provides long-term drift compensation of the receiver electronics. The compensation is achieved by means of injecting a frequency shifted CW signal into the detection channel. The algorithm running on a FPGA discriminates the two sets of amplitudes an phases. The algorithm also calculates and applies the weighted correction to measured RF signals. In the contribution we present preliminary results of the module.



Actively and passively stabilized module

$(\varphi_{cc} - \varphi_{pc}) - (\varphi_{rr} - \varphi_{pr})$
$= \boxed{\varphi_c - \varphi_r = 0}$

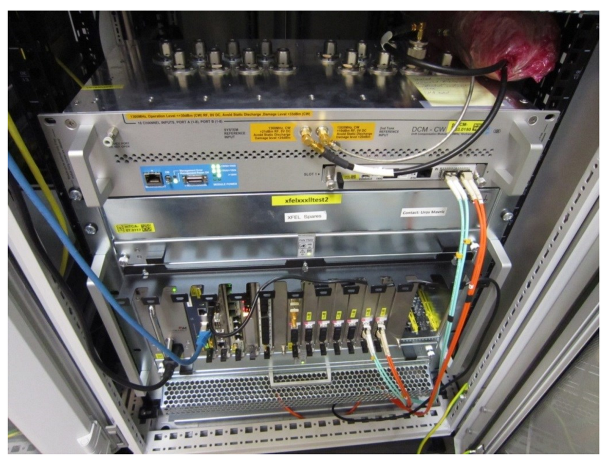
...under assumptions:

- The f_0+df sees the same phase differences as the f_0
- The first splitter for f_0 is perfect

1.3GHz CW machine operation

Investigated points

- Long-term drift as a function of pilot frequency
- Long-term drift as a function of pilot power
- Long-term drift as a function of pilot quality
- Compensation of 1/f noise with DCM-CW
- Compensation of external disturbances with DCM-CW
- Reference tracking vs. DCM-CW
- First steps towards integration into a LLRF system



Summary

- For the presented setup the optimal pilot frequencies are in regions of **3.9-4.5 MHz** and **5.8-6.5 MHz**
- The optimum power of the pilot is at its maximum (**+10dBm** input into the DCM)
- The suppression of disturbances over band **~10Hz-100kHz are 30-40 dB**
- The suppression of disturbances over band **< 0.1Hz are 20 dB (noise) and 30 dB (discrete components)**
- It is **not yet understood** of what quality has to be the pilot for best performance
- Under optimized conditions for reference tracking the correction with pilot-injection performs **3 x better** compared to reference tracking
- It was possible to achieve a stability of **$10mdeg_{pp}$** in 5h ($2.5degC_{pp}$, $13\%[RH]_{pp}$)
- We have to **change the bandwidth** of the receivers in FPGA in order to get best performance

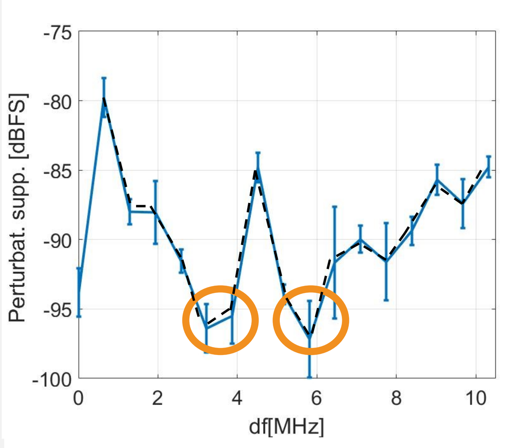
Characterization with fast perturbation

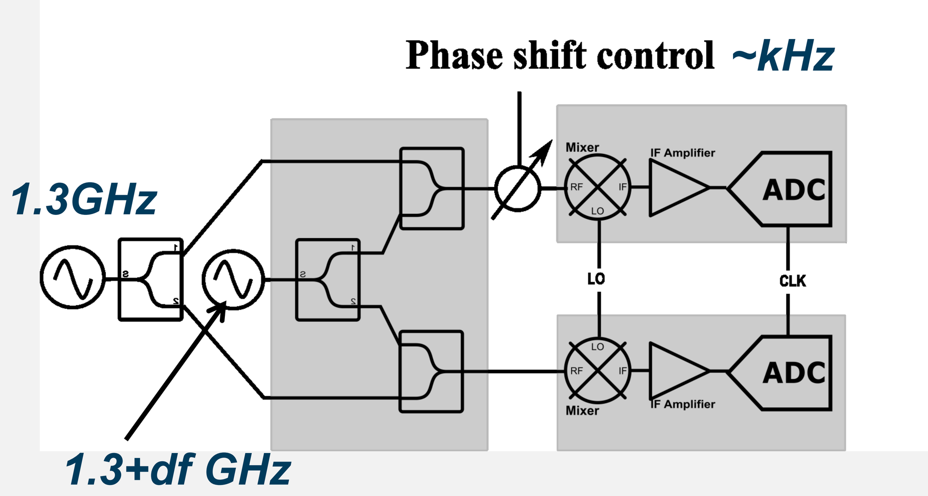
Frequency sweep

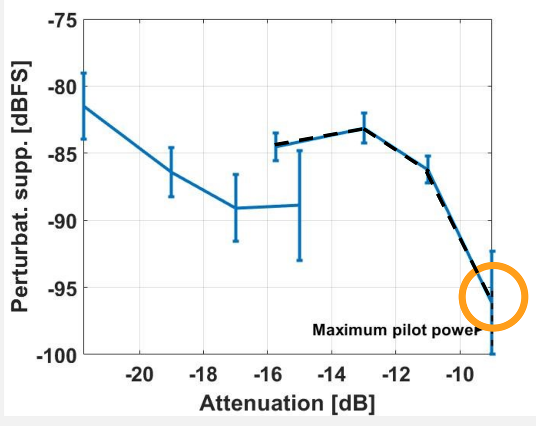
- A perturbation of 10 kHz was injected in the "cavity" channel
- The pilot frequency was swept in a range of [0-11 MHz]
- The pilot-frequencies at highest supp. are identified

Power sweep

- A perturbation of 10 kHz was injected in the "cavity" channel
- The pilot power was swept (-9 / -22dB)
- The pilot-power which gives the highest supp. are identified







Characterization with slow perturbations

Frequency sweep

- Each measurement point took 30 min.
- The perturbation is induced externally ($2.5degC_{pp}$, $10\%RH_{pp}$)
- Correlation between fast and slow method is shown (--)

Power sweep

- Each measurement point took 30 min.
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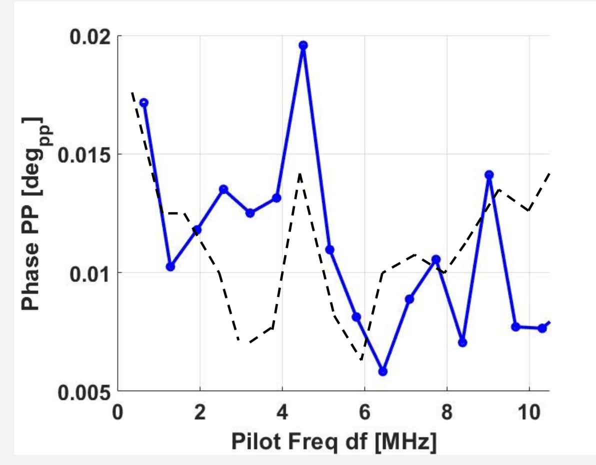
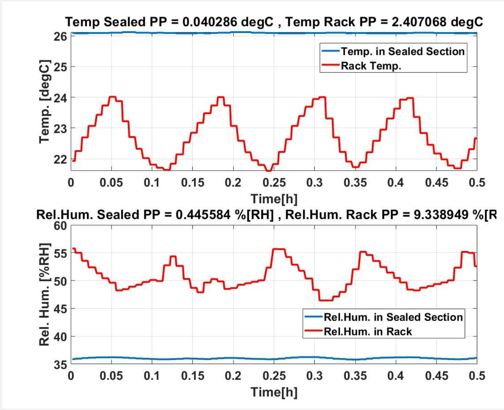
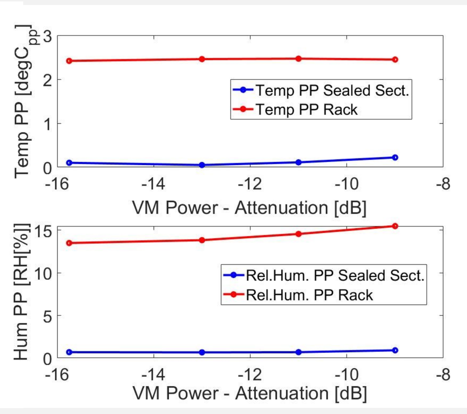
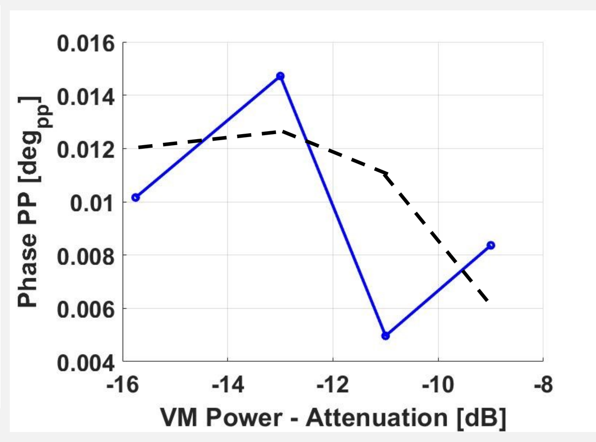








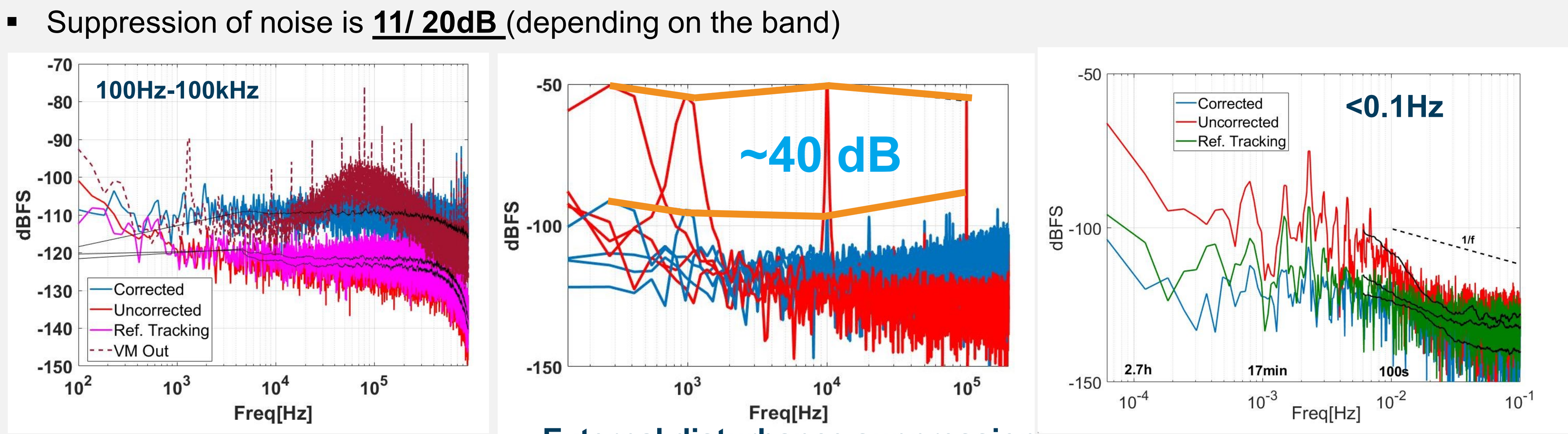
Suppression of external disturbances

Suppression of channel disturbances (100 Hz – 100 kHz) – e.g. DC/DC switching frequency

- The suppression of externally induced **discrete disturbances** is **30-40dB** over the band
- **Increase of noise-floor by 14dB** (3dB for reference tracking). ..BUT..
- The "imperfections" of the pilot are not visible on the corrected signal

Suppression of long-term disturbances (< 0.1 Hz) – e.g. drifts

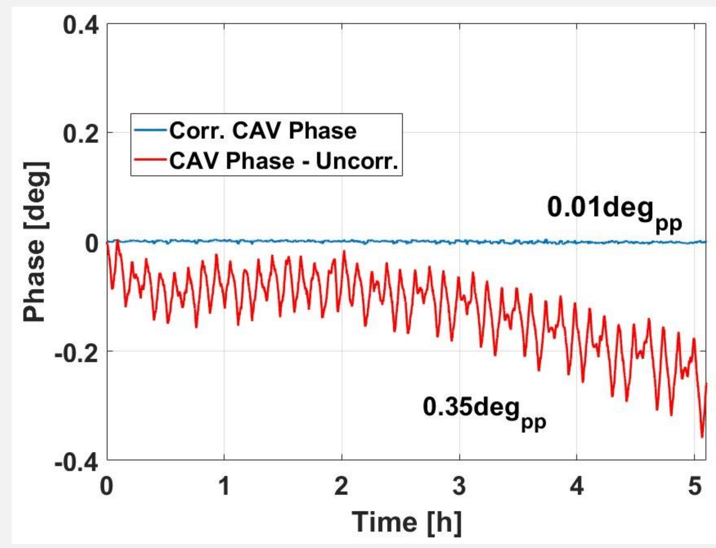
- The spectrum was calculated using the "5h" data
- The suppression of the rack temperature oscillations (discrete disturbances) is **30dB**
- Suppression of noise is **11/ 20dB** (depending on the band)

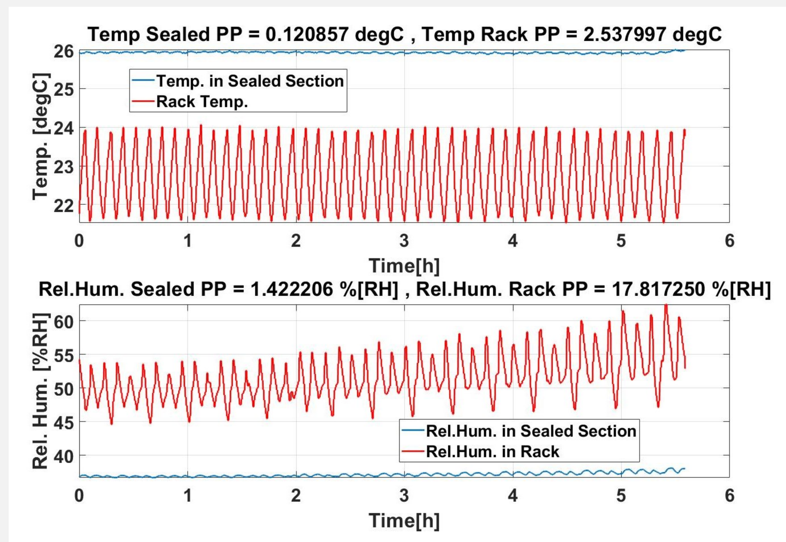


External disturbance suppression

5h measurements

- Optimized parameters as presented above
- Standard Rittal crate regulation (2.5degC_pp, 18%[RH]_pp)
- The measured stability is **10mdeg**





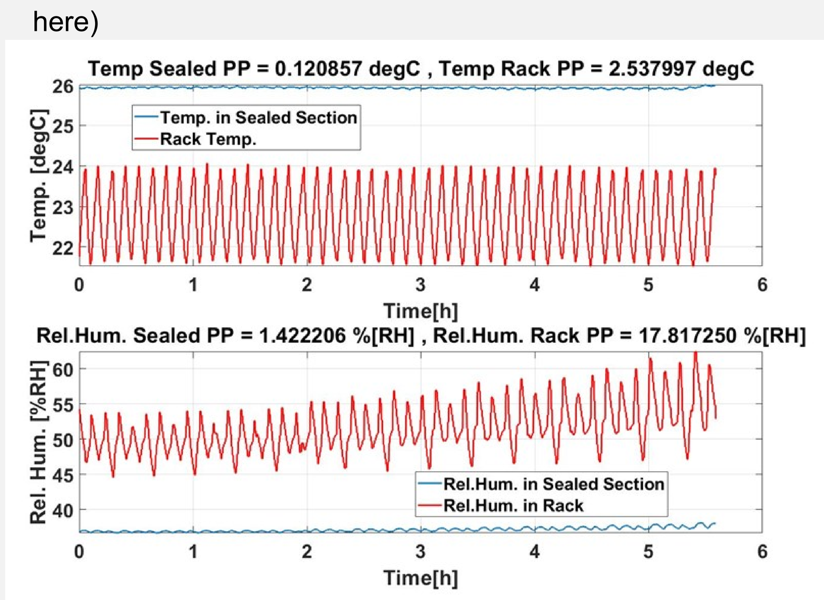
Comparison with reference tracking

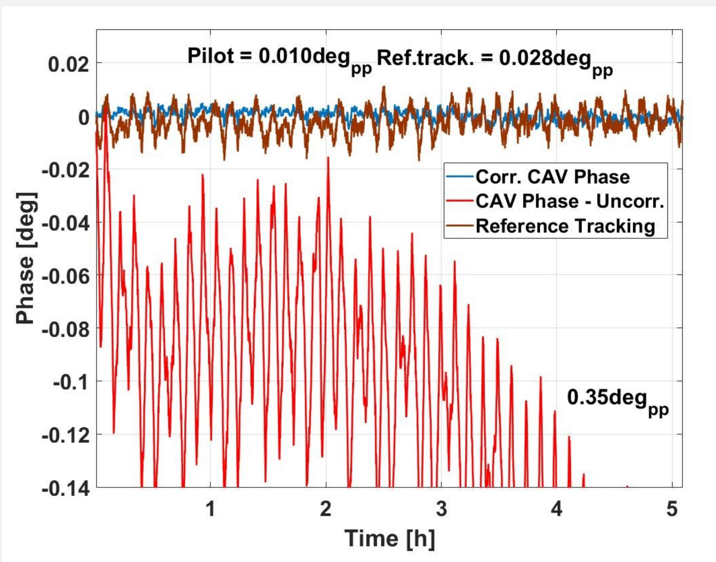
Advantages of injected-pilot over reference tracking

- > 100Hz : Channel asymmetry is not affecting compensation (suppression up to 40 dB of discrete components)
- < 0.1Hz : Larger reduction of noise (x2) and discrete components (e.g. oscillations of temperature)
- Over several hours (~5h) of measurements the measured compensation is **x2/x3 better** (depends on optimization parameters) compared to reference tracking

Disadvantages of injected-pilot over reference tracking

- Increase in broad-band noise floor (>100Hz) because of uncorrelated noise contributions -> **to be investigated**
- The spectrum of the signal is now "contaminated" with several other frequency components -> non-linear effects (not studied here)





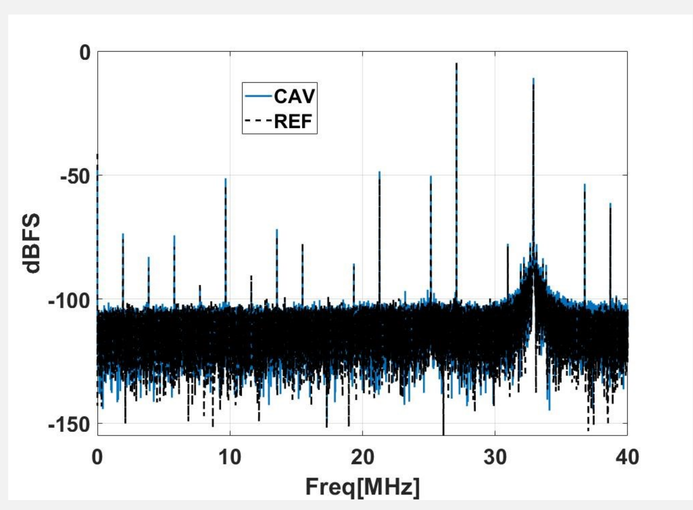
Integration into a standard LLRF system

Receiver in FPGA

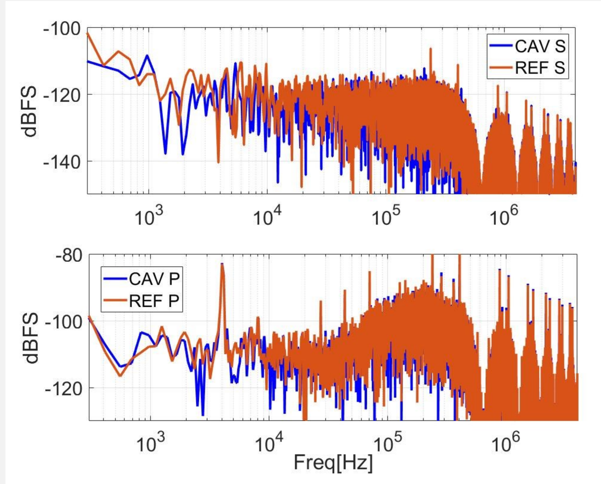
- Decimation by 9 is no longer possible -> **df ~ 9 or 4.5 MHz** (bad spots to work in!)
- Both receivers (for pilot and signal) must have the same delay -> common denominator between 3 (DESY , XFEL scheme) and N (f_s/N*M = df) -> N=9,M=1 -> df = 9 MHz (bad spot!)

Source of the pilot

- Because of an increased noise floor of the corrected signal it is at this point not clear what are the requirements of the pilot signal.
- The discrete components are subtracted and seem not to have any influence on the performance (in the given bandwidth)



f_{IF} = 27 MHz, df = 5.8 MHz, ADC data



f_{IF} = 27 MHz, df = 5.8 MHz, amp and pha data for signal and pilot

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